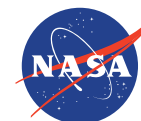


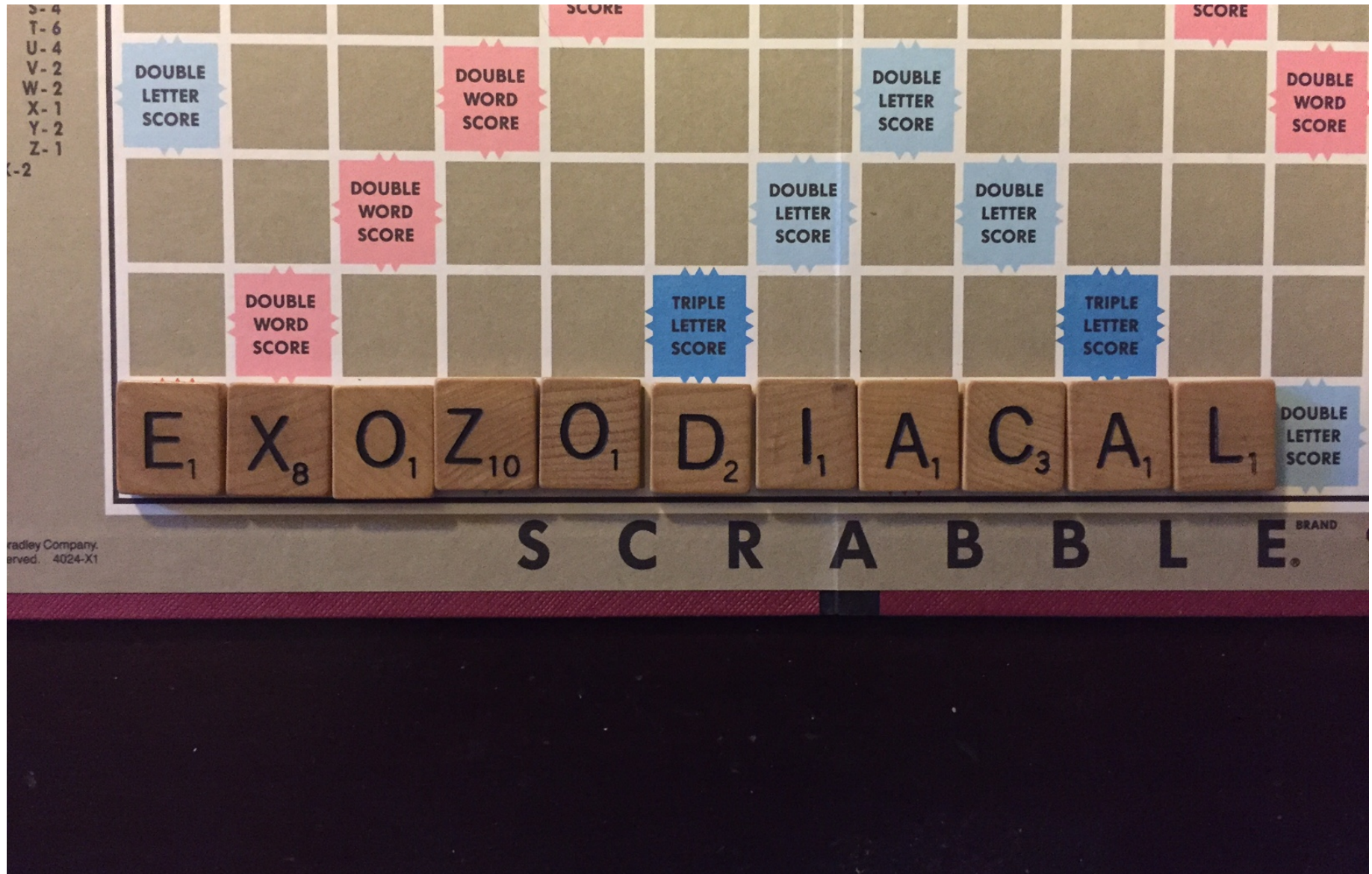
LBTI and Exozodiacal Dust

Phil Willems
Jet Propulsion Laboratory

April 6, 2018
Embry-Riddle Aeronautical
University



Jet Propulsion Laboratory
California Institute of Technology



Why Care About Dust?

Observations of
16th

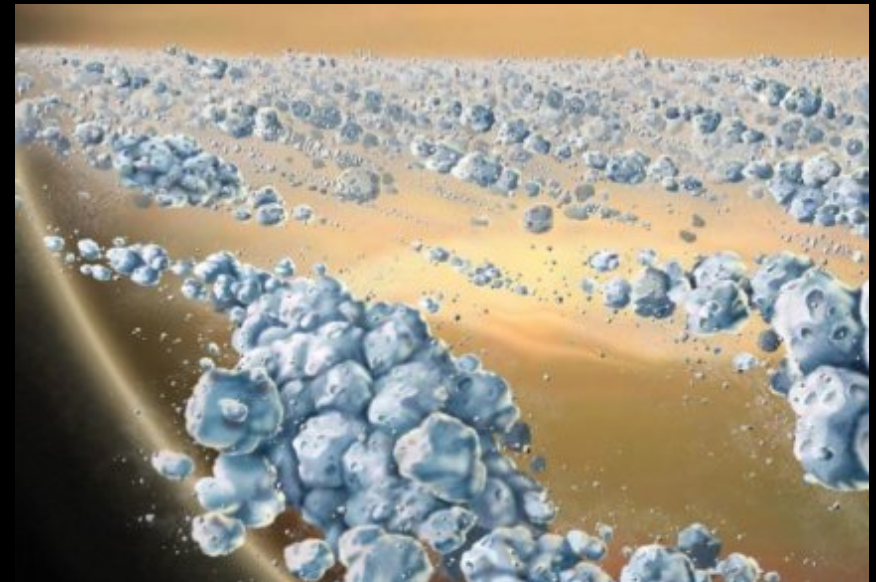
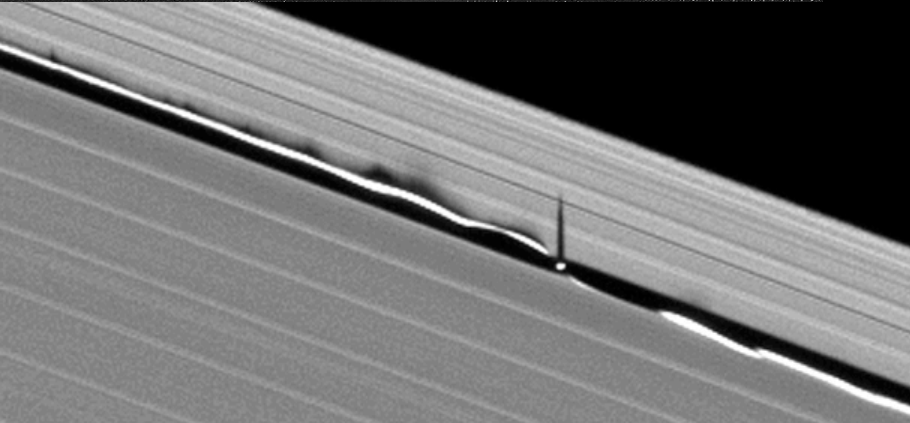
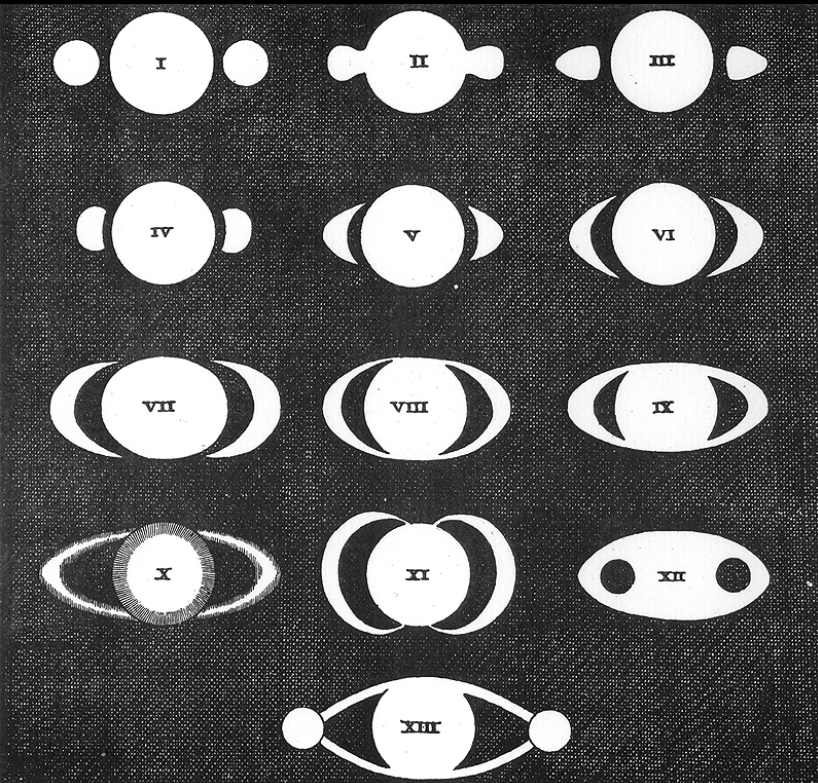
2. J. J. J.	max H. 12	○ * *
30. J. J. J.		* * ○ *
2. J. J. J.		○ * * *
3. J. J. J.		○ * *
3. H. 5.		* ○ *
7. J. J. J.		* ○ * *
6. J. J. J.		* * ○ *
8. J. J. J.	H. 17.	* * * ○
10. J. J. J.		* * * ○
11.		* * ○
12. H. 4. J. J. J.		* ○
17. J. J. J.		* * ○
14. J. J. J.		* * * ○ *



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29 March 2017

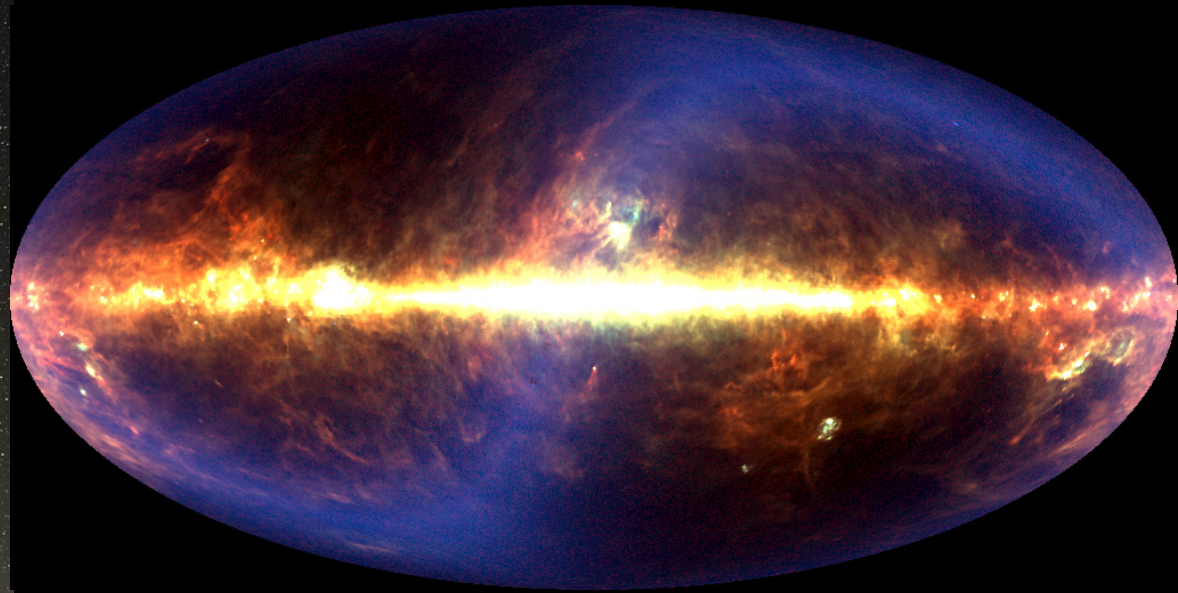
Why Care about Dust?



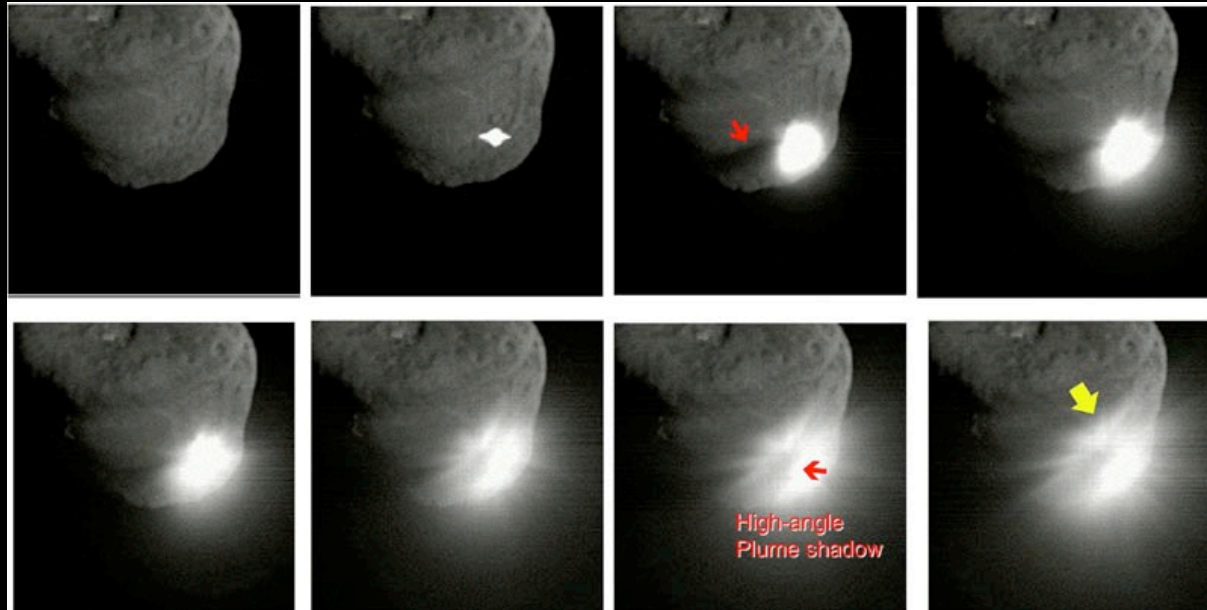
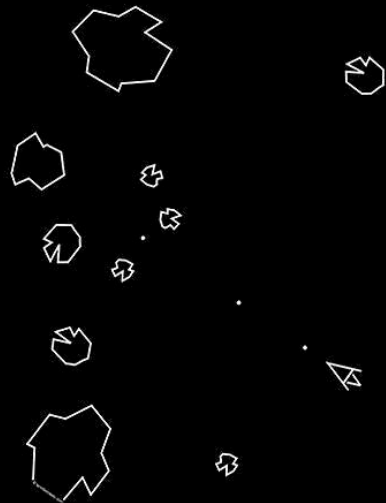
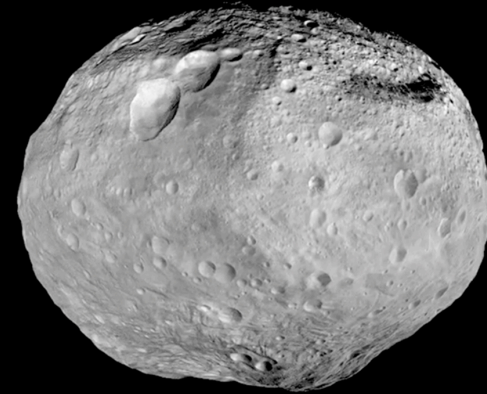
Zodiacal Dust

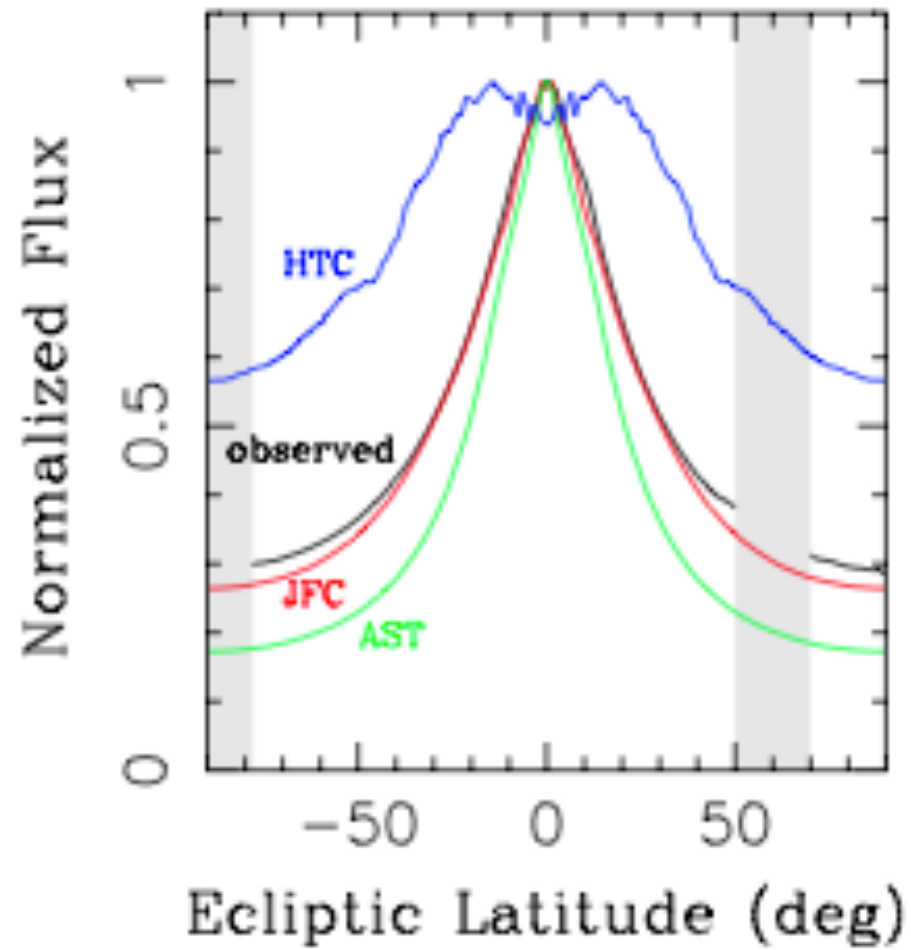


Credit: ESO/Y. Beletsky

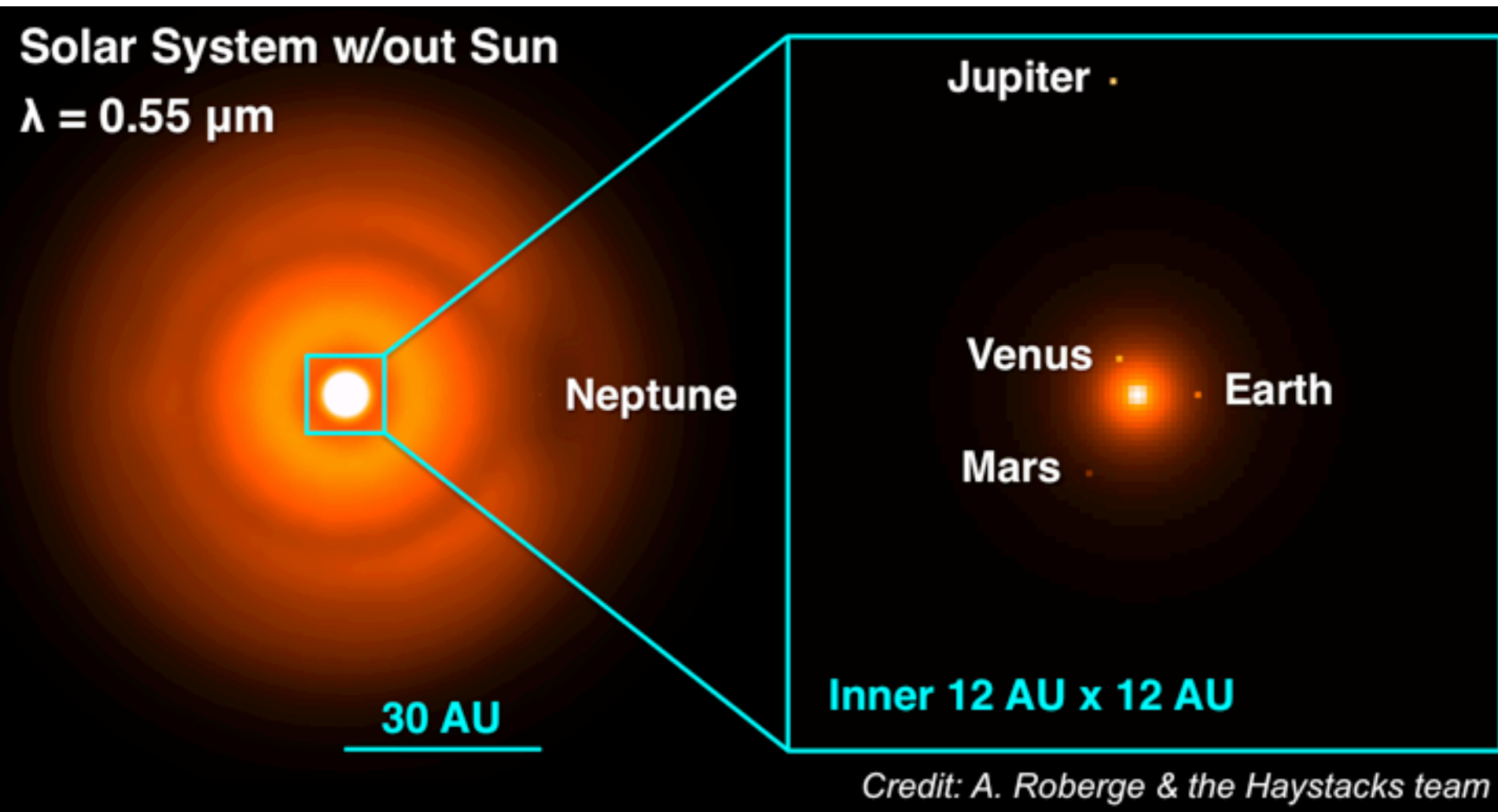


Whence the Zodiacal Dust?





From Nesvorvy et al. (2010)



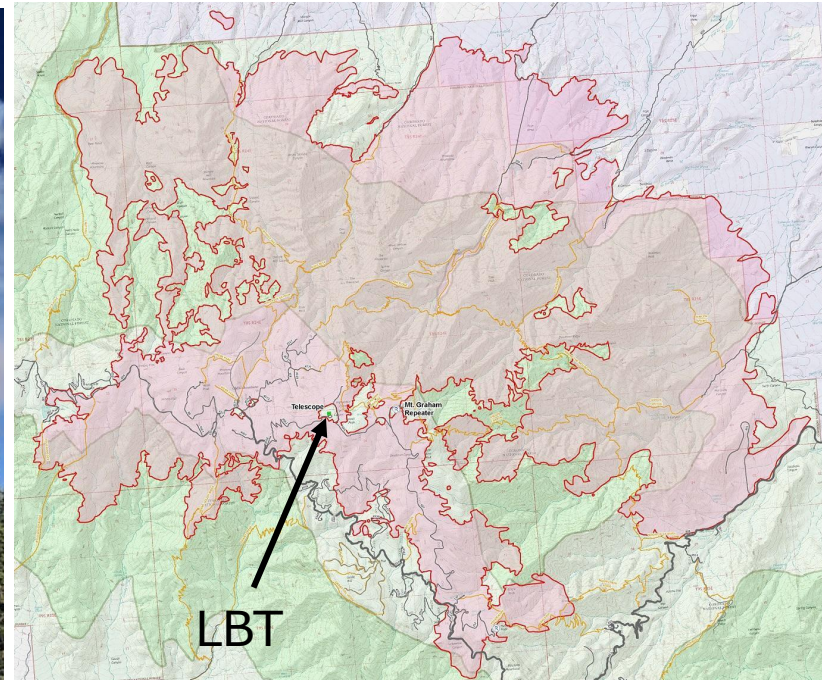


Credit: ww2today.com

Frye Fire



ExoPlanet Exploration Program



A Few Words of Gratitude



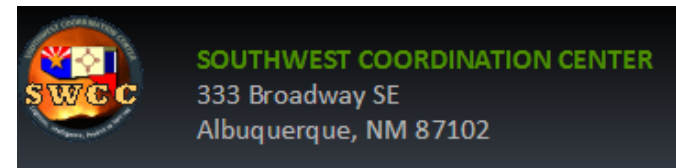
ExoPlanet Exploration Program

Great work from the Forest Service and all the fire crews involved

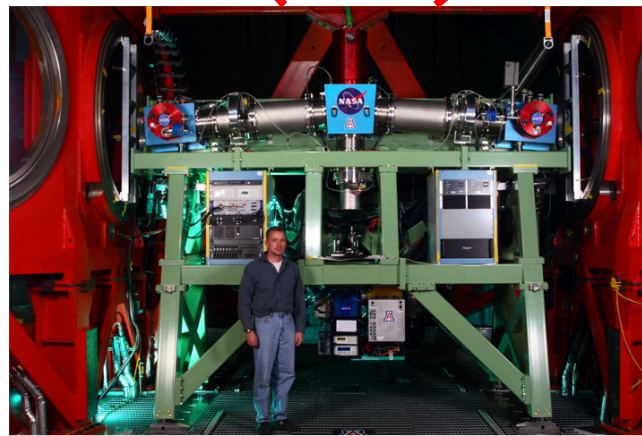
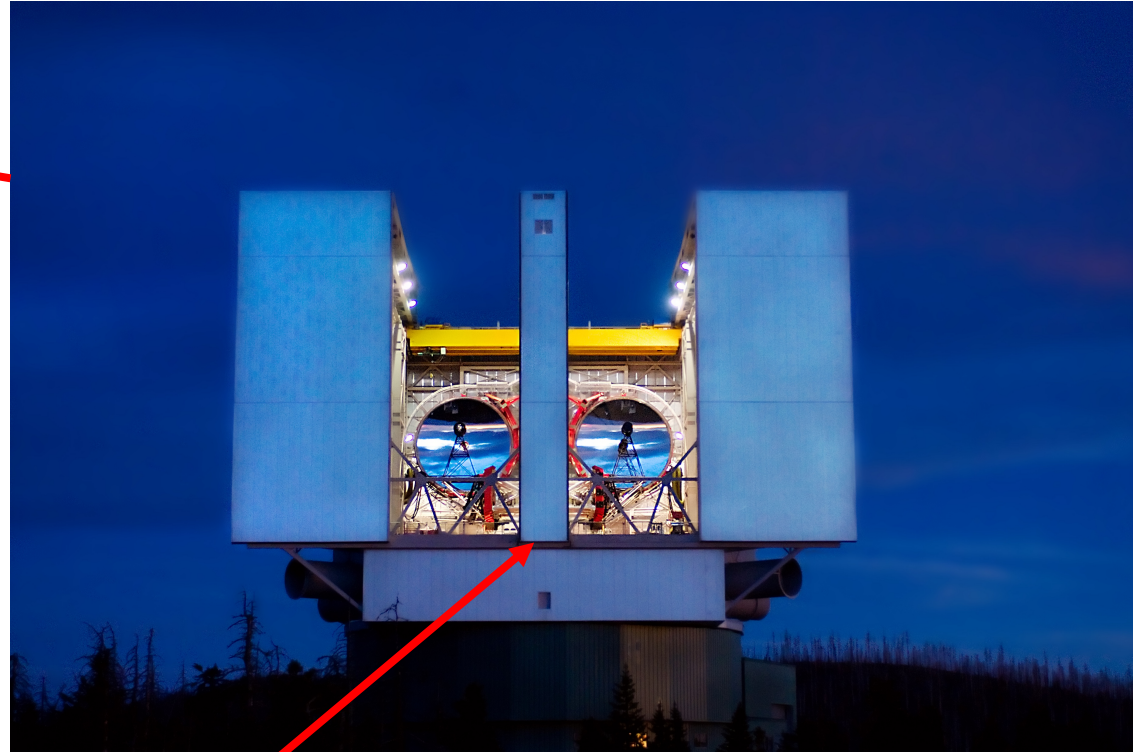
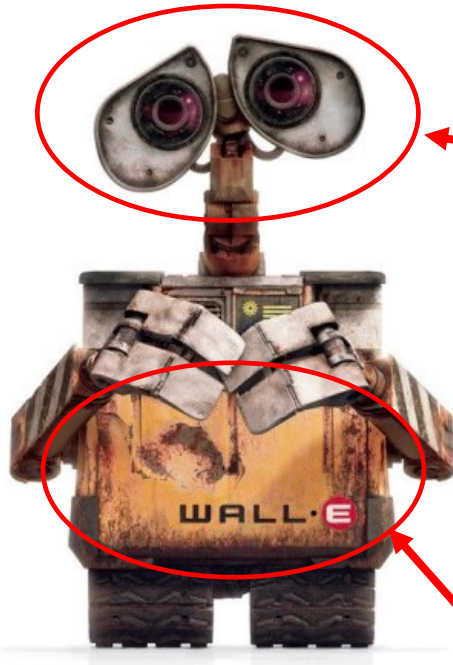
Southwest Area Type 2 Incident Management Team 3

Type 1 Northern Rockies Incident Management

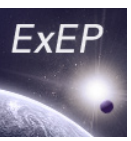
Southwest Area Type 2 Incident Management Team 5



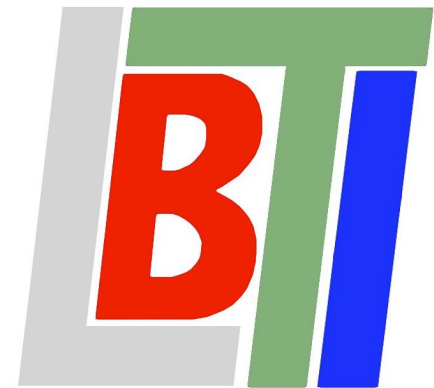
What is LBTI?



LBTI-Contributing Institutions (Phil Hinz, Principal investigator)



ExoPlanet Exploration Program



What is the Habitable Zone?



ExoPlanet Exploration Program

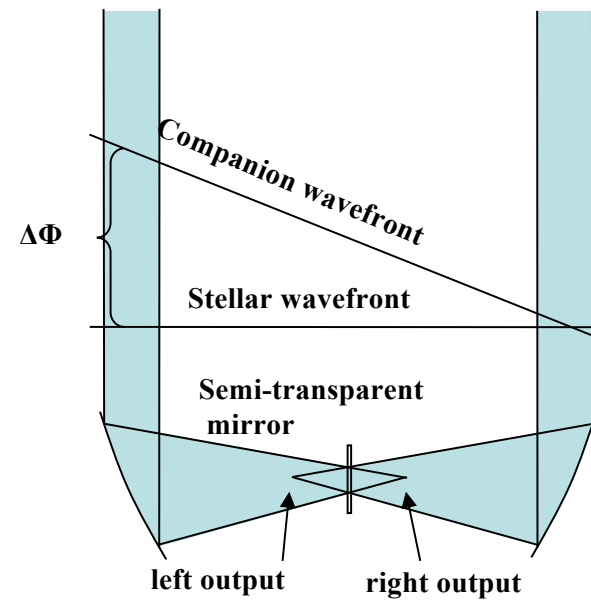
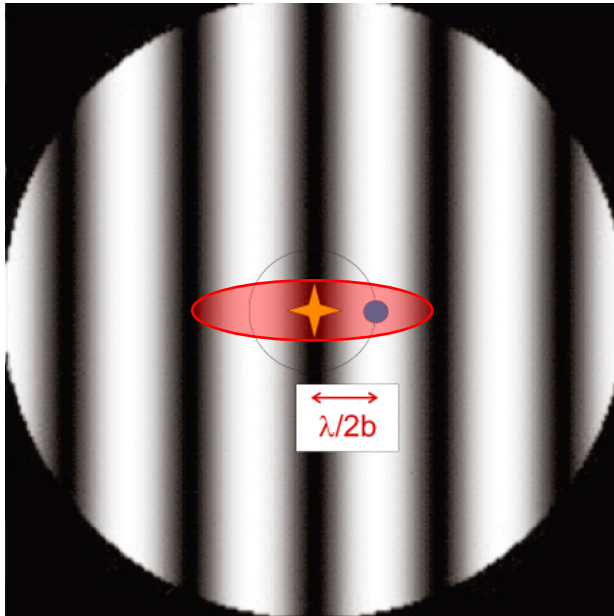


Credit: Luc Forsyth

Bracewell Nulling Interferometry



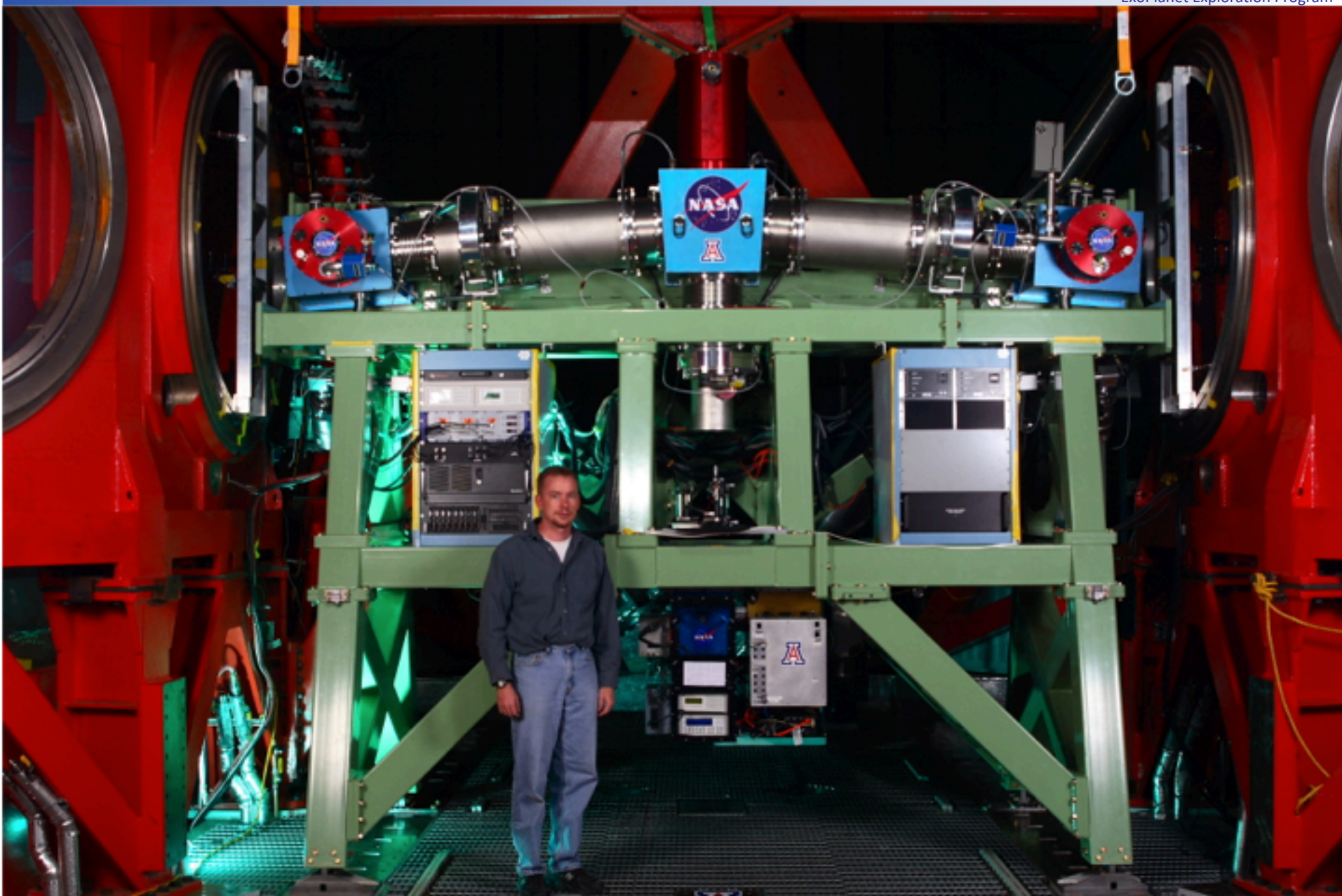
ExoPlanet Exploration Program



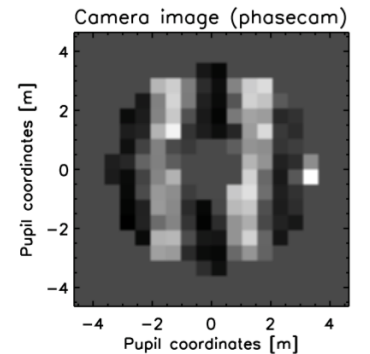
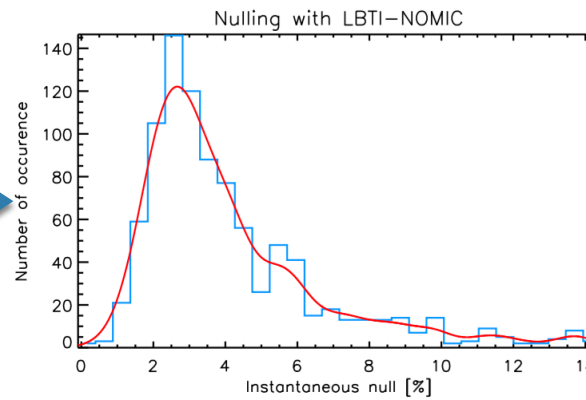
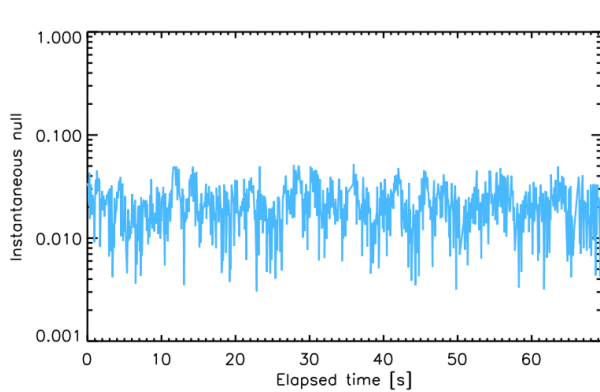
LBTI as Installed



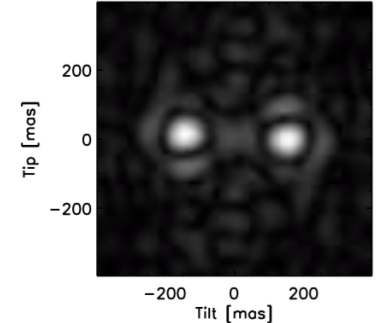
ExoPlanet Exploration Program



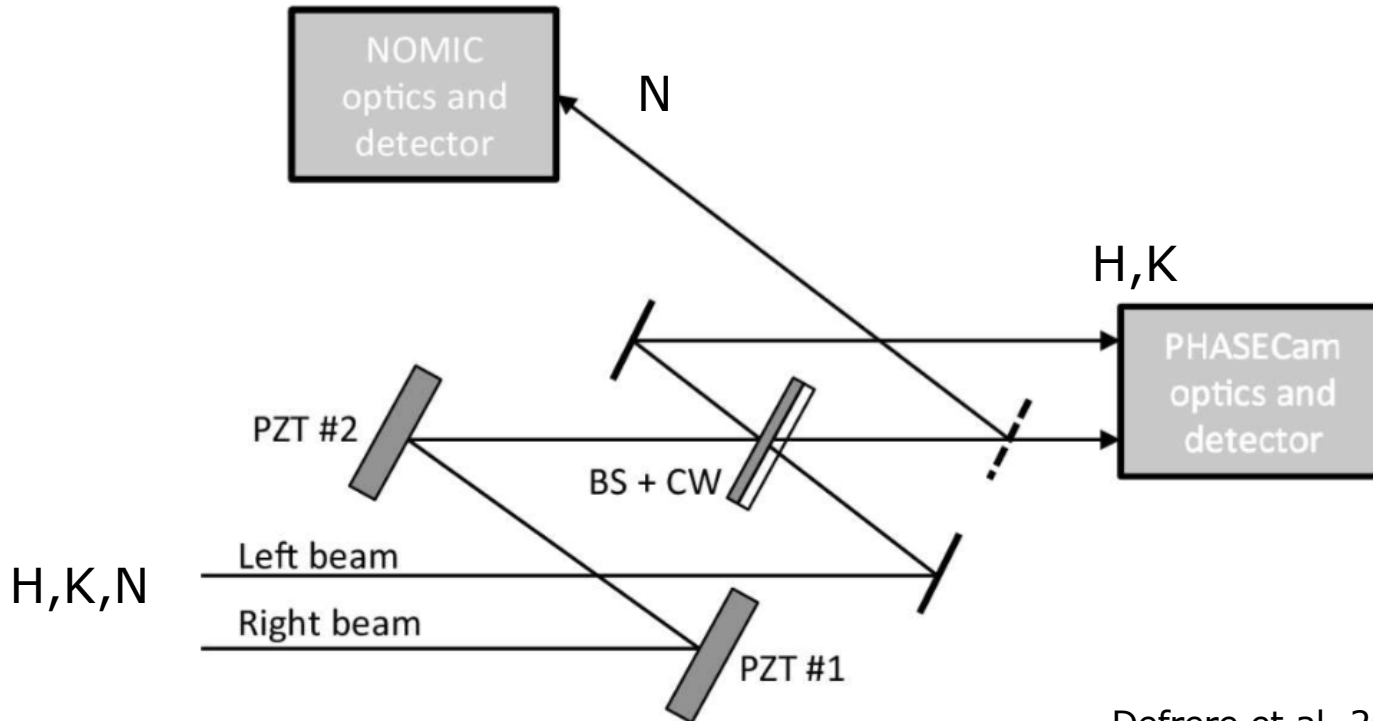
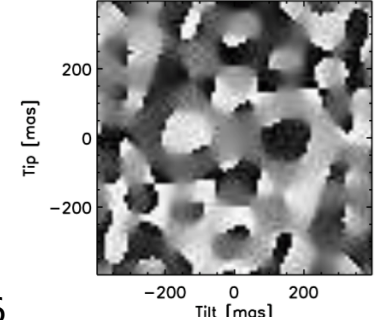
How LBTI Finds and Measures the Null



Fourier amplitude (phasecam)



Fourier phase (phasecam)



Observing Distant Room-Temperature Dust with a Room-Temperature Telescope on a Room-Temperature Planet

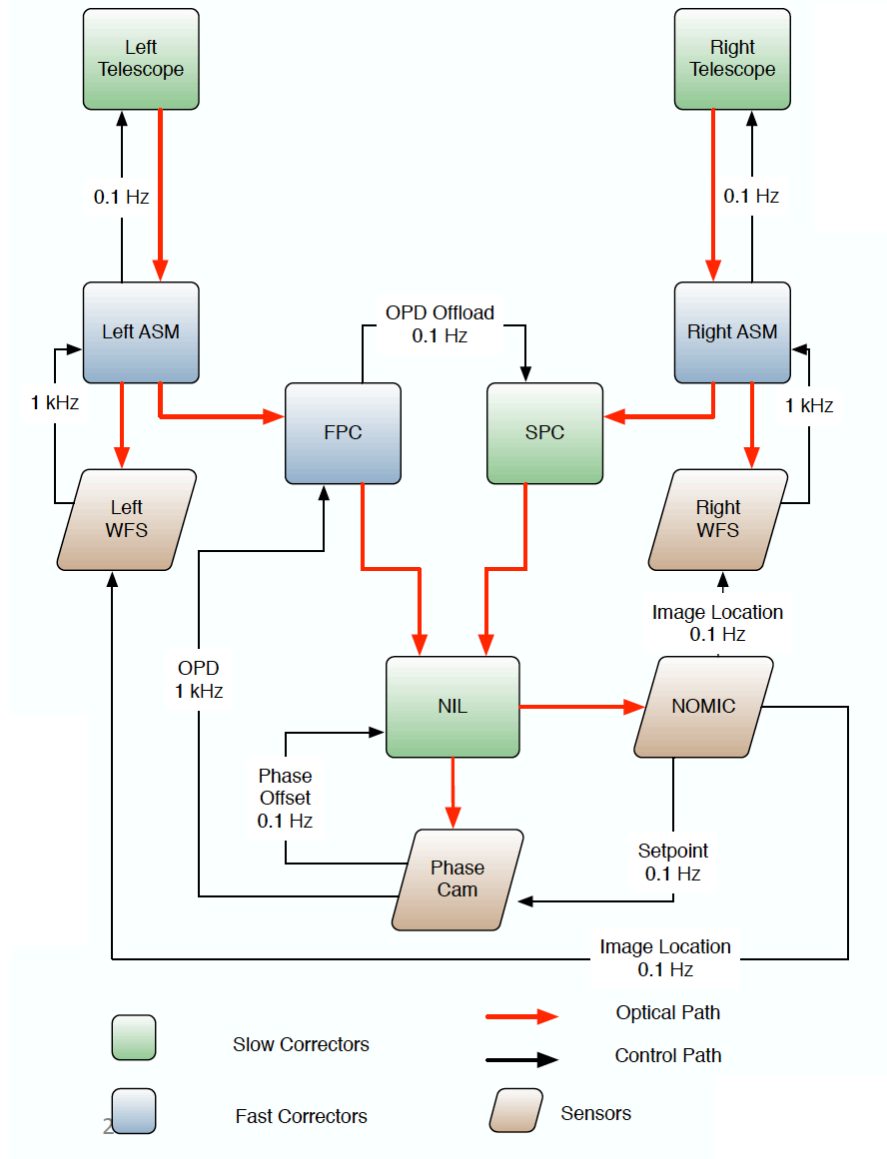


ExoPlanet Exploration Program

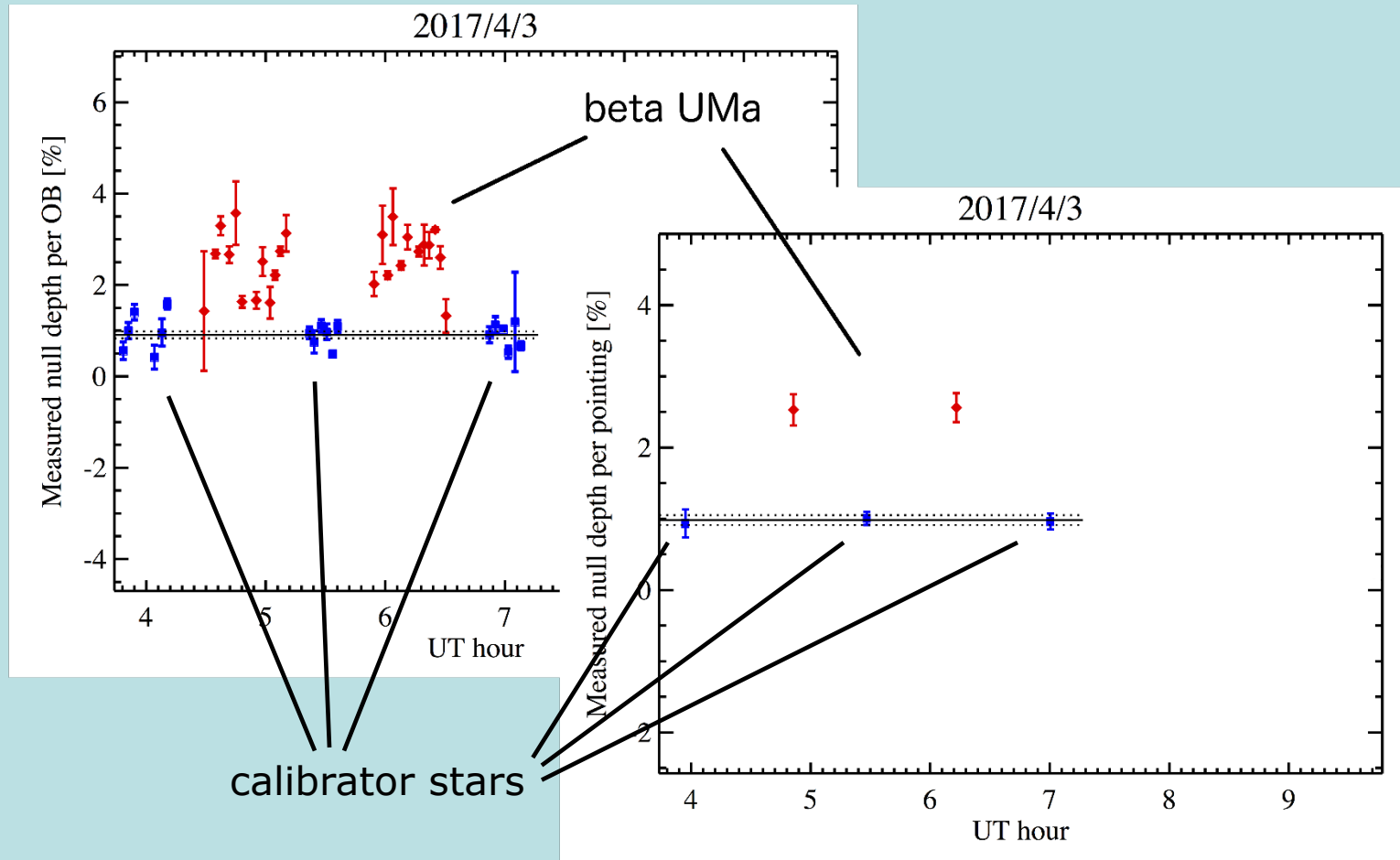
- For exozodi at 10's of Solar System levels, the raw SNR is 10^{-6} . To see anything, LBTI must:
 - Suppress thermal background in the detector by cooling to $\sim 6\text{K}$
 - Suppress thermal background in the beam combining optics by cooling to $\sim 77\text{K}$
 - Avoid observing through high cirrus cloud 'greybodies'
 - Nod telescope between two nearby orientations- while one ROI of the detector measures signal+background, the other ROI measures only background (and vice-versa for 2nd half of nod)
 - Further estimate background in signal ROI by measuring pixels surrounding ROI.

- Imperfectly Overlapping Wavefronts
 - Adaptive secondary mirrors correct atmospheric turbulence
- Mismatching Pupil Powers
 - Measurements of calibrator stars account for this
- Precipitable Water Vapor
- Vibrations

Servos, Servos, Servos

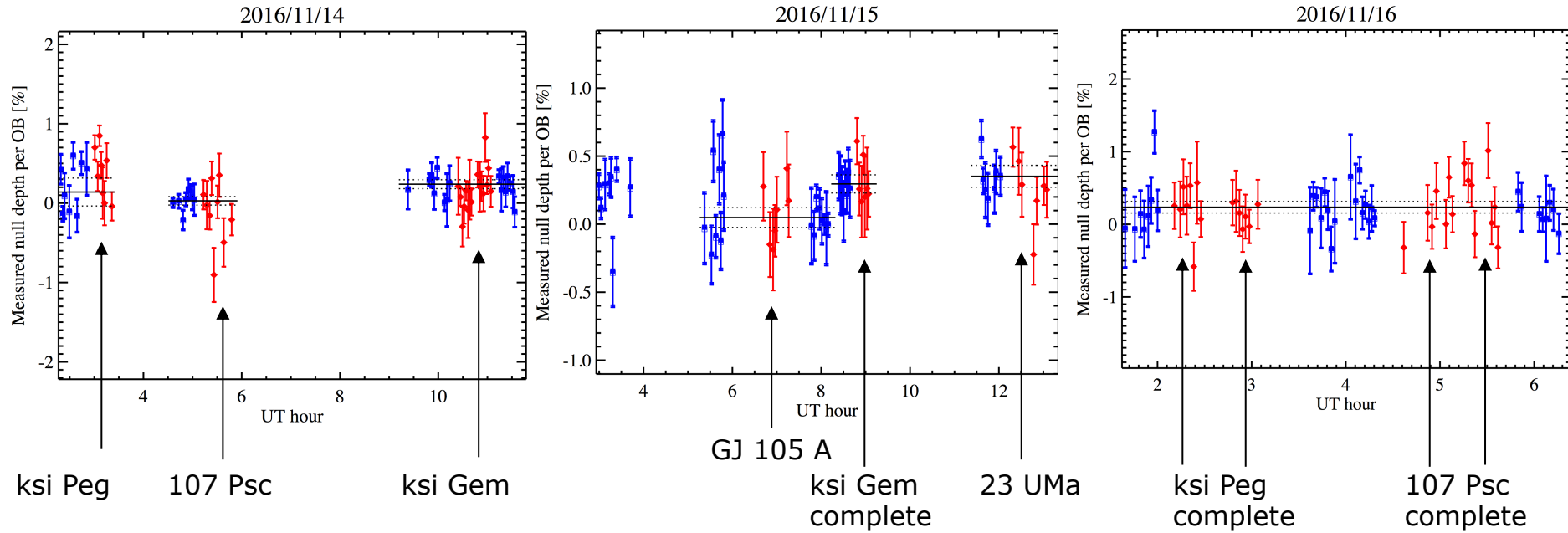


LBTI Detection of Exozodi Around β UMa



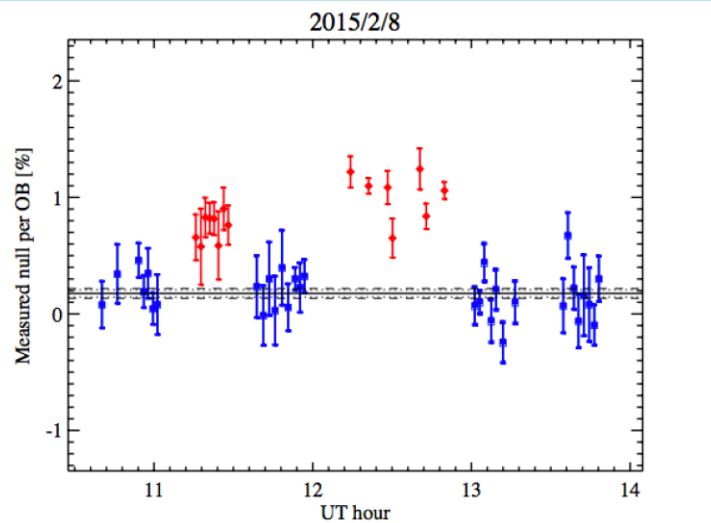
Preliminary result: 142 ± 15 zodis

Most of the Stars LBTI Looks at Are Clean



red=science stars
blue=calibrator stars (no resolvable dust)

Another dirty star: beta Leo



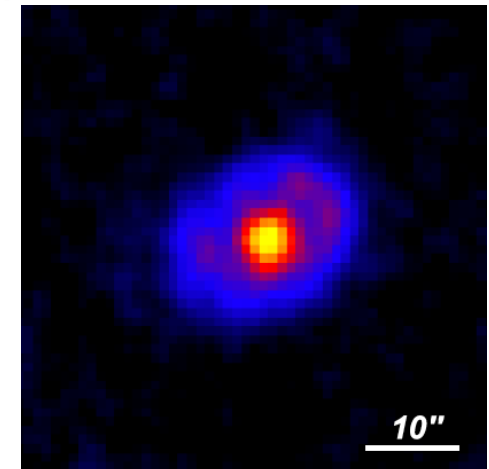
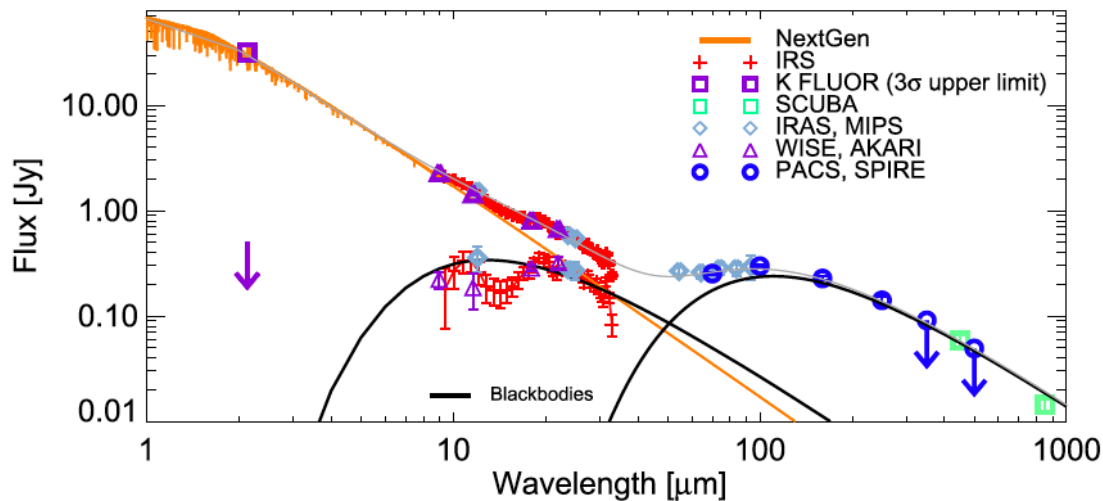
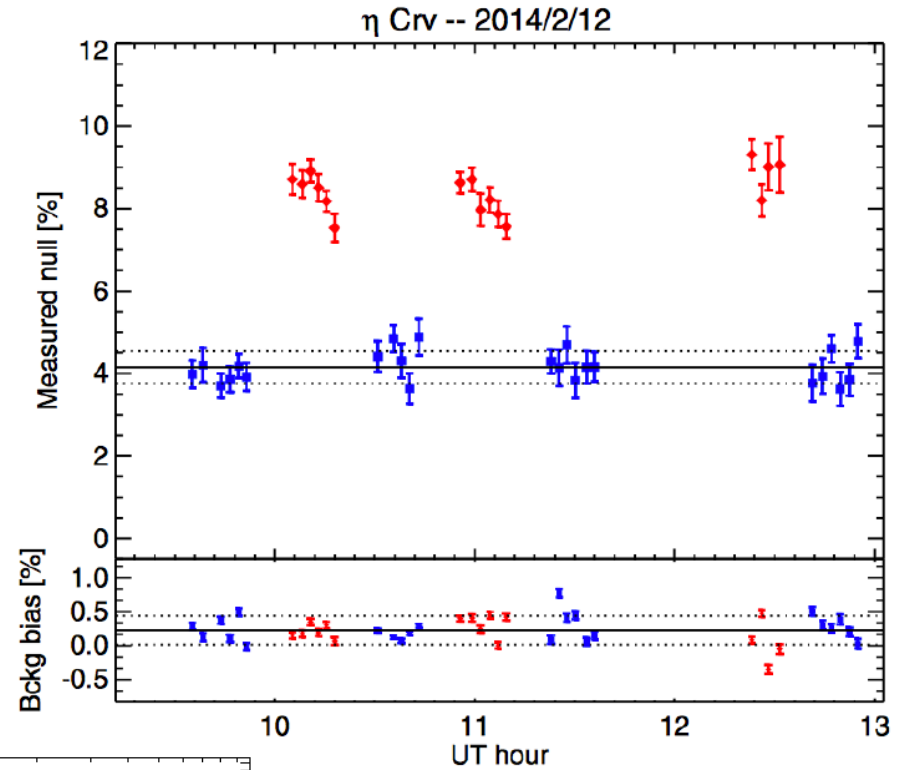
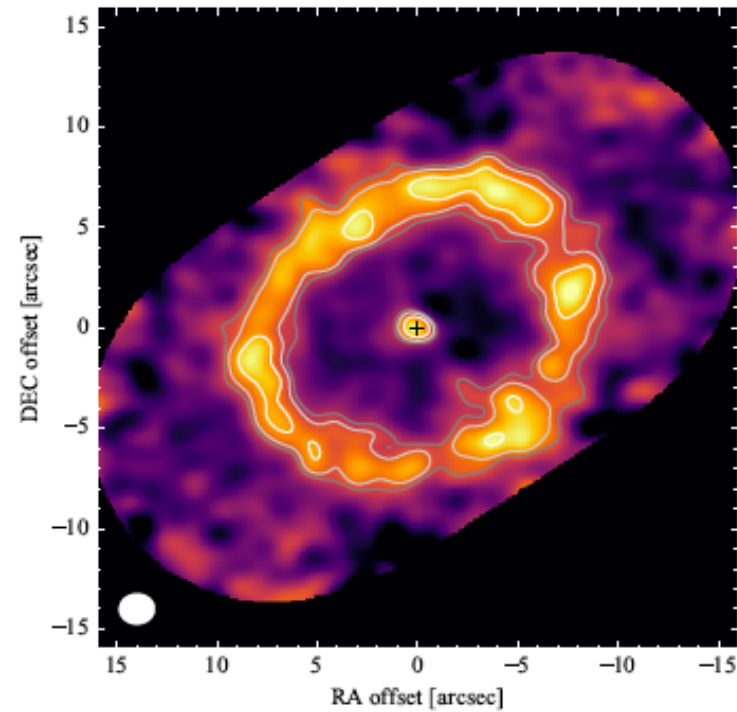
90 \pm 8
zodis

HOSTS Survey Data So Far

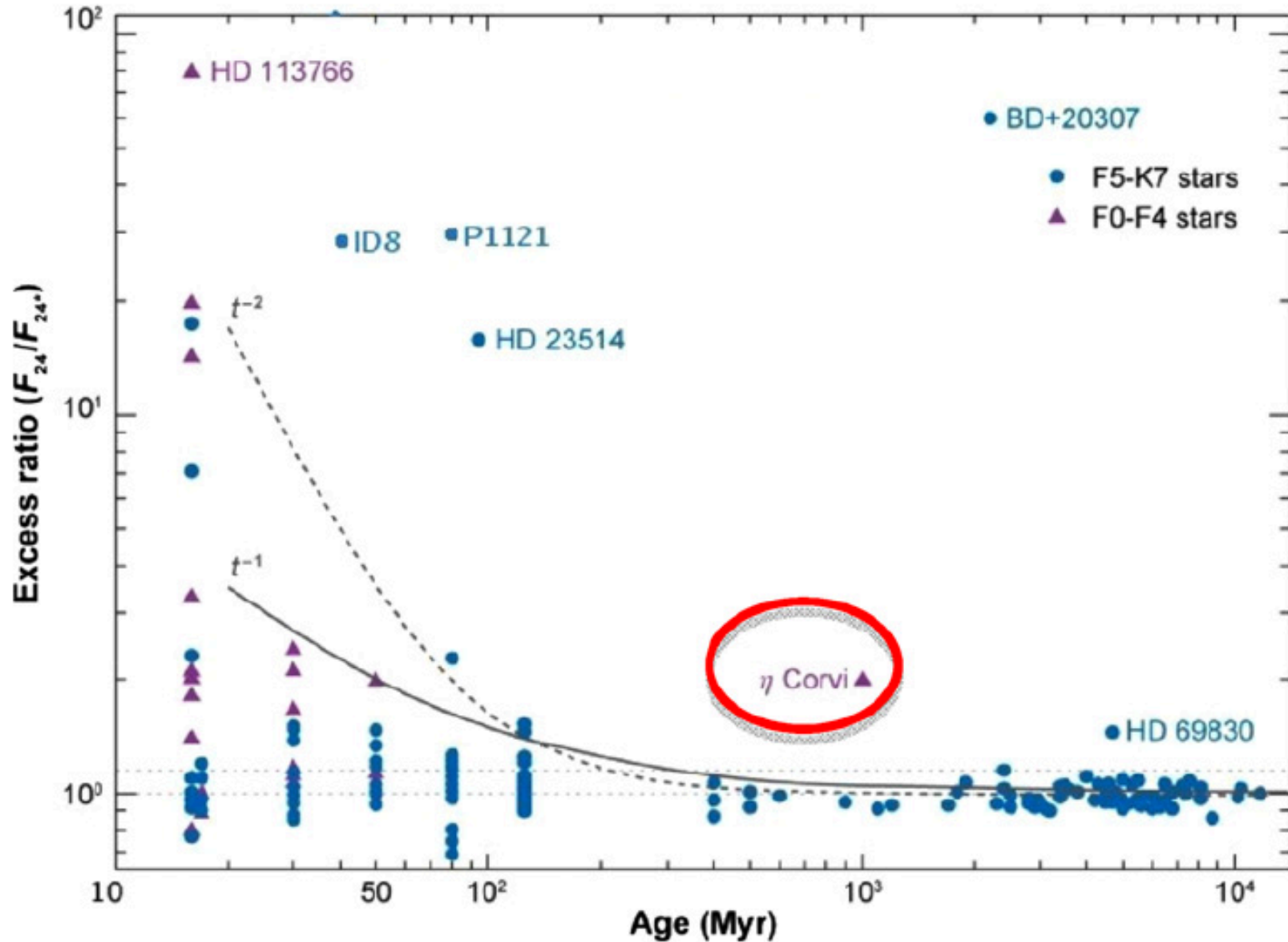
Table 2. Null measurements and zodi levels.

Aperture →		8 pix		13 pix		Conservative								
HD number	Name	$N_{\rm as}$ (%)	σ_N (%)	$N_{\rm as}$ (%)	σ_N (%)	$r_{\rm ap}$ (pix)	$N_{\rm as}$ (%)	σ_N (%)	aperture for zodi	$N_{\rm as,1}$ (%)	z (zodi)	σ_z (zodi)	z/σ_z	
Sensitivity driven sample (Spectral types A to F5):														
33111	β Eri	-0.004	0.110	0.168	0.119	18	0.372	0.176	13 pix	4.45×10^{-3}	37.8	26.7	1.4	
81937	23 UMa	0.003	0.073	0.013	0.092	25	0.008	0.179	13 pix	2.60×10^{-3}	4.9	35.3	0.	
95418	β UMa	0.920	0.055	1.019	0.060	33	1.655	0.102	13 pix	6.49×10^{-3}	156.9	9.2	17.1	
97603	δ Leo	0.028	0.051	0.033	0.055	32	-0.013	0.143	13 pix	5.49×10^{-3}	6.1	10.0	0.6	
103287	γ UMa	-0.037	0.033	0.003	0.031	35	0.083	0.080	13 pix	7.02×10^{-3}	0.4	4.4	0.1	
106591	δ UMa	0.366	0.094	0.436	0.109	28	0.523	0.184	13 pix	5.12×10^{-3}	85.2	21.2	4.0	
108767	δ Crv	-0.333	0.131	-0.243	0.199	26	0.933	0.365	13 pix	7.45×10^{-3}	-32.6	26.8	-1.2	
128167	σ Boo	-0.019	0.096	-0.006	0.118	22	0.417	0.252	13 pix	2.10×10^{-3}	-2.7	56.0	-0.1	
129502	μ Vir	-0.006	0.092	0.183	0.110	25	0.192	0.198	13 pix	1.95×10^{-3}	93.8	56.7	1.7	
172167	α Lyr	-0.037	0.050	0.022	0.061	37 ^a	0.240	0.150	13 pix	4.62×10^{-3}	4.7	13.1	0.4	
187642	α Aql	-0.032	0.166	0.217	0.192	47 ^a	-0.995	0.356	13 pix	3.84×10^{-3}	56.5	50.1	1.1	
203280	α Cep	-0.301	0.376	-0.233	0.182	18	-0.075	0.266	13 pix	3.36×10^{-3}	-69.4	54.3	-1.3	
Sun like stars sample (Spectral types F6 to K8):														
10476	107 Psc	-0.028	0.083	-0.027	0.122	21	0.154	0.181	13 pix	6.36×10^{-4}	-42	192	-0.2	
16160	GJ 105 A	0.228	0.232	-0.227	0.239	18	0.538	0.363	13 pix	4.49×10^{-4}	-506	533	-1.0	
30652	1 Ori	0.098	0.183	0.347	0.217	28	0.209	0.351	13 pix	2.27×10^{-3}	152.5	95.3	1.6	
34411	λ Aur	-0.210	0.095	-0.108	0.079	22	0.041	0.136	13 pix	1.16×10^{-3}	-93.3	68.3	-1.4	
48737	ξ Gem	0.048	0.099	0.124	0.098	27	0.057	0.229	13 pix	2.20×10^{-3}	56.4	44.6	1.3	
88230	GJ 380	-0.111	0.059	-0.077	0.056	20	-0.189	0.087	13 pix	2.59×10^{-4}	-299	217	-1.4	
89449	40 Leo	0.238	0.263	-0.018	0.290	21	1.278	0.578	13 pix	1.51×10^{-3}	-12	192	-0.1	
120136	τ Boo	-0.046	0.191	-0.313	0.148	22	0.343	0.456	13 pix	1.50×10^{-3}	-208.3	98.7	-2.1	
126660	θ Boo	0.276	0.082	0.362	0.085	24	0.362	0.103	13 pix	1.55×10^{-3}	234.0	54.8	4.3	
141004	λ Ser	0.015	0.036	0.025	0.047	23	-0.107	0.117	13 pix	1.20×10^{-3}	21.0	39.2	0.5	
142373	χ Her	-0.063	0.052	0.112	0.061	22	0.071	0.083	13 pix	1.13×10^{-3}	99.7	53.7	1.9	
142860	γ Ser	0.037	0.044	-0.009	0.058	25	0.023	0.079	13 pix	1.78×10^{-3}	-4.9	32.4	-0.2	
173667	110 Her	0.126	0.096	0.101	0.115	24	0.561	0.157	cons.	1.98×10^{-3}	283.3	79.0	3.6	
185144	σ Dra	0.027	0.052	-0.075	0.071	22	-0.096	0.096	13 pix	8.82×10^{-4}	-85.4	80.7	-1.1	
215648	ξ Peg A	0.154	0.121	0.226	0.167	23	0.198	0.214	13 pix	1.61×10^{-3}	140	103	1.4	
Commissioning targets:														
22049	ϵ Eri	0.037	0.147	0.206	0.142	27	0.901	0.269	cons.	1.24×10^{-3}	724	216	3.4	
102647	β Leo	0.470	0.050	0.420 ^b	0.054	32	1.160	0.333	8 pix	4.00×10^{-3}	117.4	12.5	9.4	
109085	η Crv	4.410	0.350	4.580 ^b	0.460	24	4.710	0.890	8 pix	1.67×10^{-3}	2649	210	12.6	

η Corvi, a Very Untidy Star



Cold Debris Has a Short Lifespan



Where Does the Dust Go?



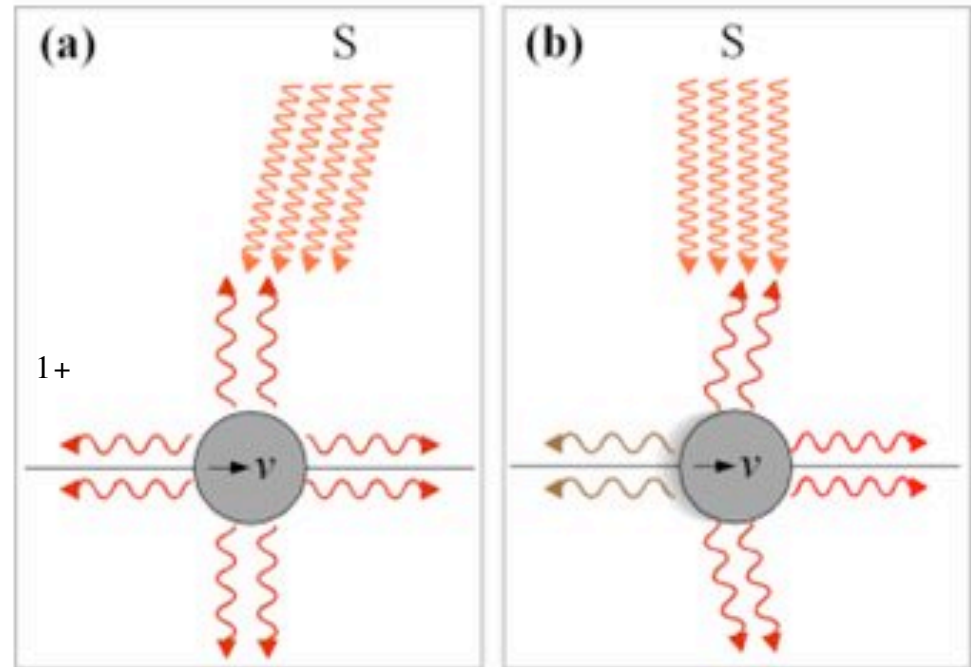
Radiation Blowout



Credit: tonymetone

Meteors

Poynting-Robertson Drag

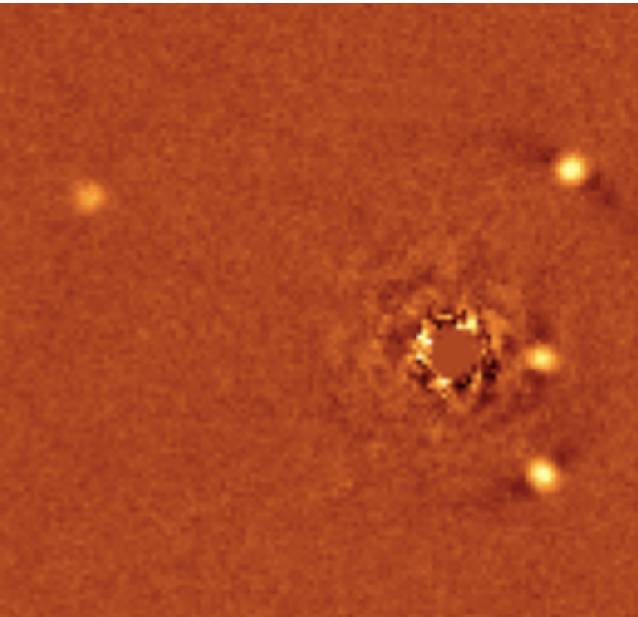


$$\tau_{PR} = \frac{4\pi a \rho_d c^2 D^2}{3L_{star}}$$

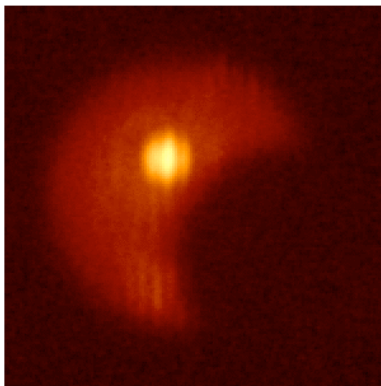
LMIRCam, an L- and M-band Imager/Spectrometer/Interferometer



ExoPlanet Exploration Program

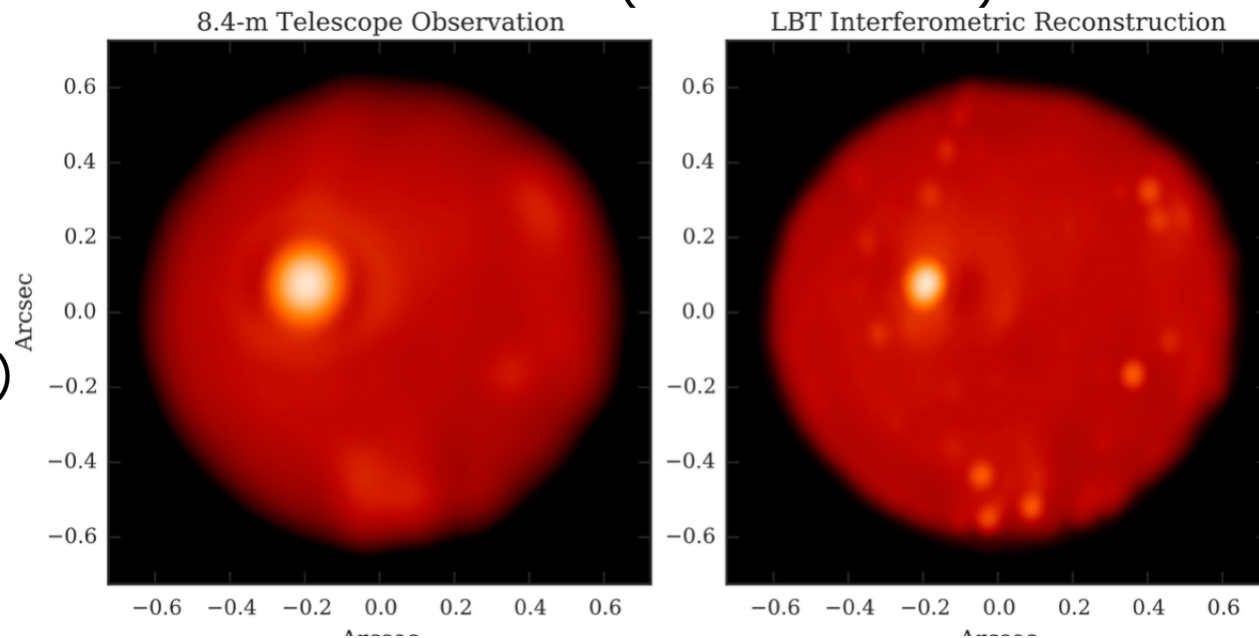


HR8799 (Maire et al.)



Europa occultation of Io (credit: LBTO)

Io (credit: P. Hinz)



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